Enhancing wheat yield and sustainability: A long-term study comparing conventional and conservation agriculture management practices with varied crop sequences and irrigation methods

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Abstract

This long-term five years research project (2013-2018) investigated agronomic and profitability aspects of irrigated wheat production in conventional and conservation agriculture (CA) managements including varied crop sequences under normal and terminal drought irrigation methods. The experimental design was a split plot in RCBD with four replicates consisting conventional and CA based managements, six crop sequences and two irrigation methods of normal and terminal irrigations in fixed permanent plots at Karaj in Alborz province, Iran. Agronomic and economic analysis used analysis of variance and partial budgeting technique. The results showed that there were no significant effects for means of wheat grain yield among conventional and CA managements, but the means for wheat grain yield in CA management was 5.2 percent more than conventional agricultural management during experiment period. The profitability for crop sequence of wheat/maize -canola/maize (WMCM) under normal irrigation method and CA management was more than other studied crop sequences. The estimated mean for the present value of gross profit for the irrigated wheat cv. Parsi for the studied crop sequences and under normal irrigation was 22.53 Iranian million rials per hectare during experimental period. Comparison of the two conventional and CA managements showed that the substitution of crop sequence of wheat/maize -canola/maize (WMCM) by other crop sequences was not economical, because of decrease in the mean of present value of gross profit.

Keywords: Irrigated wheat, Crop management, Cropping sequence, Terminal drought, Conservation agriculture, Economic assessment

Introduction

A range of studies have explored the impact of different agricultural management practices on wheat yield and sustainability. Lark (2020) found that treatment differences in maize yield varied by cropping season, with a strong benefit of rotation in El Niño seasons. However, there was no overall advantage of residue-retaining systems over conventional management. Hochman (2014) similarly emphasized the importance of cropping sequence intensity and configuration, as well as fallow management, in improving agronomic efficiency. Lacoste (2016) highlighted the influence of land types on management and grain yield variability, with rotations varying by soil type and farm type. Pradhan (2012) underscored the need for an integrated approach to revitalizing irrigation systems, including infrastructure rehabilitation, investment in yield productivity, and promotion of appropriate institutions and management modes. These studies collectively suggest that a combination of crop rotation, cropping sequence management, and irrigation system revitalization can enhance wheat yield and sustainability.

Crop rotation has indeed been practiced for thousands of years, with evidence dating back to ancient civilizations such as those in Greece and Rome. The concept involves alternating crop types grown in a particular area over different seasons or years to improve soil fertility, prevent soil erosion, control pests and diseases, and optimize yields. In ancient Greek and Roman agriculture, crop rotation was a common practice. Farmers would rotate crops such as cereals (like wheat and barley), legumes (such as beans and lentils), pulses (like chickpeas and peas), and tubers (including potatoes and yams) in specific patterns to maintain soil health and maximize productivity. These practices were often based on observations of natural cycles and the understanding that different crops have varying nutrient requirements and effects on the soil. The principles of crop rotation have continued to be refined and applied in modern agriculture, with scientific research contributing to our understanding of soil ecology, nutrient cycling, and the benefits of diversifying crop rotations. Today, crop rotation still remains an important strategy for sustainable farming practices worldwide. This historical crop rotation is comparable to contemporary crop rotations in Australian wheat fields (Sedras and colleagues, 2004). In reviewing the hidden mechanisms of crop rotation effects on the performance of target crops, recent studies have explored direct and cumulative effects, including genetic, transitional, and priming effects of crop rotations and sequences. Specifically, short-term crop sequences involving agricultural crops with cover crops have been investigated for their impact on soil properties such as quality, health, and fertility (Mehrvar et al., 2021; Boonman et al., 2018), microbial populations (mainly fungi and bacteria, and the F:B ratio) (Jamal et al., 2023), functional diversity of soil microbial populations (Zhang et al., 2019), soil microbiome ecosystem services (Zeghe and colleagues, 2019), rhizosphere microbiome, and crop health (Bergersen et al., 2012), soil fertility, greenhouse gas emissions, and the interplay of various factors in conventional and agroecological management and sustainable agriculture (Wessel et al., 2014). The effects of crop rotations and sequences on minimum tillage, no-till management, diverse crop residue managements, diversity in crops and cover crop species before main crop wheat, and the duration of their retention in agricultural land, along with the introduction of new crop species and varieties into the cropping system, remain significant research challenges (Carlen et al., 1994). The phenomenon known as the "rotation effect" has long been recognized as a key driver of yield increase in crop rotations (Bullock, 1992). However, elucidating a single underlying mechanism responsible for this phenomenon remains elusive. Multiple factors have been identified as contributing to the rotation effect, including improvements in soil physical properties, reduced pressure from weeds, pests, and diseases, and enhanced microbial biodiversity (Bullock, 1992; Karlen et al., 1994a). Additionally, crop rotations have been shown to have positive impacts on environmental quality, particularly through reductions in nitrogen (N) fertilizer inputs, especially when incorporating legume crops into the rotation (Pedersen and Lauer, 2003; Stanger and Lauer, 2008). This reduction in N fertilizer usage has been associated with a consequential decrease in the emission of the potent greenhouse gas nitrous oxide (N2O) (Bayer et al., 2015; Drury et al., 2008; Omonode et al., 2011), which possesses approximately 300 times the global warming potential of carbon dioxide (CO2) (IPCC, 2013). Moreover, the utilization of legume crops as a nitrogen source warrants consideration, particularly in light of volatile fertilizer prices that fluctuate annually (USDA-ERS, 2011).

The use of crop sequences with main crops such as wheat and green manure cover crops has been proposed as an essential cropping system for ecological management of agricultural ecosystems. While it may not be a complete substitute for crop rotations in moderate climates in short-term cycles, it can be introduced as a complementary approach to the crop sequences presented in this article, particularly the two-year sequence of wheat/forage maize-canola/forage maize in a conservation cropping system (Mehrvar et al., 2021). According to our findings, supported by the research conducted by Chen et al. (2021), the application of green manure prior to planting maize, wheat, and potato main crops in Northern China yielded significant and beneficial effects. This practice substantially improved soil quality and enhanced crop performance. Specifically, it led to a reduction in soil bulk density by up to 5.6%, a notable increase in soil microbial biomass carbon by up to 28%, and a considerable enhancement in soil enzyme activity ranging from 14% to 39%. Among the diverse green manure cover crops studied, leguminous varieties notably augmented soil nitrate and hydrolysable nitrogen levels, while non-leguminous types significantly boosted soil potassium content. However, it's noteworthy that soil water content decreased with green manure treatments. Notably, maize crop performance exhibited a remarkable 11% increase due to green manure treatment, though the impact on yields varied for wheat and potato crops, showing contradictory results.

Drawing from a comprehensive four-year investigation into the impact of green manure cover crop treatments on wheat grain yield, our statistical analysis unveiled no significant effects attributable to these treatments nor to the interaction between cover crop and year. However, a notable revelation emerged: the yearly fluctuations wielded a highly significant influence on wheat grain performance, suggesting the existence of enduring legacy effects. These enduring effects were traced back to the meticulous execution of crop sequences and rotations. Notably, while crop

rotations exerted a lasting influence solely in the temporal dimension, they effectively perpetuated the influence of green manure across the experimental plots throughout the entirety of the study, as highlighted by Mehrvar et al. (2021).

Soil, which sustains nearly all daily caloric intake worldwide, embodies a critical lifeline for humanity. However, mounting concerns regarding nutrient depletion and ecological repercussions loom large, particularly exacerbated by contemporary agricultural methods reliant on synthetic fertilizers, pesticides, and herbicides. This perilous trajectory endangers crucial soil microbes, resulting in far-reaching consequences such as arable land degradation and water contamination. Regrettably, the wisdom ingrained in historical agricultural techniques, prioritizing soil vitality through diverse cropping practices, has largely faded into obscurity amidst the dominance of modern industrial agriculture. Monoculture, a hallmark of this modern approach, renders farms increasingly vulnerable to diseases, with the potential to devastate vast swathes of crops in the event of a pathogen outbreak. Conversely, the implementation of crop rotation and diverse farming methodologies stands out as a beacon of hope, offering avenues to mitigate soil erosion, reintroduce organic matter, and restore nutrient levels sans the reliance on artificial inputs.

Numerous studies underscore the profound impact of crop sequences on soil dynamics and agricultural sustainability. For instance, Drinkwater et al. (1998) elucidated how appropriate crop sequences influence nitrogen stabilization and availability, vital for subsequent crops. Similarly, Bending et al. (2007) documented the effects of crop residues and root exudates on soil pH, shedding light on the intricate mechanisms at play. Moreover, Smith et al. (2014) explored the role of crop sequences in improving soil structure through enhanced aggregate formation, emphasizing the significance of root architecture. Basche et al. (2016) further highlighted the role of cover crops in reducing soil erosion, underscoring the importance of vegetative cover in preserving soil integrity.

Furthermore, the detrimental effects of continuous monoculture on soil microbial communities have been extensively studied, with Hartman et al. (2008) demonstrating the adverse repercussions on microbial diversity and nutrient cycling. Conversely, Mazzola (2004) observed improvements in crop health resulting from disruptions in the life cycle of soil-borne pathogens and pests. Weston (1996) also investigated the allelopathic effects of cover crops, offering insights into weed suppression and microbial modulation.

Understanding these phenomena necessitates a holistic approach, as emphasized by Brandsen et al. (2012) and Clark et al. (1998), who highlighted the role of crop sequences in enhancing soil microbial diversity and carbon cycling. Additionally, adopting conservation tillage practices, as demonstrated by Koch et al. (2002), Derpsch et al. (2010), and Erosk and Papendick (1992), contributes to improved water efficiency and soil structure, crucial for sustainable agriculture. Moreover, the intricate interactions within the rhizosphere microbiome, elucidated by Berg and Smalla (2009) and Mendes et al. (2011), underscore the importance of microbial management for long-term agricultural sustainability.

The impacts of climate change on agriculture, including shifts in temperature and precipitation patterns, pose challenges that necessitate adaptive strategies to maintain crop productivity (Crawford et al., 2013; Hatfield et al., 2017; Lobell et al., 2011). The interactive crop rotation effects, conservation tillage, soil microbial population dynamics, and the integration of main and cover crops as a comprehensive approach in sustainable agriculture are evident. These practices not only enhance soil health but also contribute to improved water efficiency, nutrient cycling, and pest management. Given the global challenges posed by climate change, adopting resilient and adaptable agricultural strategies to preserve and enhance crop productivity is crucial. The findings of these studies underscore the need for a comprehensive and integrated approach to cropping in irrigated farms, emphasizing the vital role of soil microbial populations and the adoption of sustainable practices to shape the future of agriculture.

While the overall economic impact of crop sequences depends on market conditions for crops within the crop sequence, agricultural diversity can contribute to economic resilience. Desirable cropping practices, incorporating crop residues into the soil and its nutrient management, play a crucial role in minimizing negative environmental impacts and promoting overall production system sustainability (Smith et al., 2008).

Crop sequences may influence soil microbial populations differently for each crop. Diverse crops within agricultural sequences can increase microbial diversity of the soil and contribute to nutrient cycling and overall soil health.

Additionally, different root structures and residue characteristics of wheat, maize, and canola can impact soil structure. Precise cropping, including residue decomposition and organic matter composition, can influence soil physical properties (Ferar et al., 2007).

Due to distinct growth cycles and physiological characteristics, wheat, maize, and canola exhibit different water requirements. Planning crop sequences with careful consideration of water availability and efficiency is crucial. The root systems of these crops can influence soil water infiltration and retention, thereby contributing to overall water use efficiency (Passioura, 2007). Crop sequences leverage complementary growth stages. For instance, Fall-cropped wheat utilizes the autumn and early spring seasons, while summer-cropped maize thrives in warmer months. Decomposition of crop residues in crop sequences helps accumulate nutrients in the soil, potentially benefiting subsequent crops (Derpsch et al., 2010).

Crop sequences can influence the dynamics of insect populations, as different crops attract or repel specific pests. Agricultural diversity may support overall biodiversity, benefiting beneficial organisms and wildlife in agricultural landscapes (Letourneau and Goldstein, 2001).

Crop sequences can impact soil organic carbon balance. Diverse crop residues contribute to varied soil organic carbon content, potentially increasing carbon sequestration. Incorporating conservation tillage inside crop sequences can enhance soil health, reduce erosion, and contribute to the overall sustainability of cropping (Lal, 2004).

Including different crops with varying water needs in crop sequences can aid in overall system resilience against water scarcity or drought cycles. Agricultural diversity facilitates adaptation to temperature fluctuations, as each crop has its preferred temperature range for growth (Lobell *et al.,* 2011).

Crop sequences may influence weed dynamics, and if not managed correctly, the growth of certain agricultural crops may favor specific weed species, requiring appropriate weed control strategies (Orzak *et al.,* 1994).

Economic resilience of cropping systems depends on market conditions for wheat, maize, and canola. Agricultural diversity can act as a buffer against market fluctuations. Precise management of input costs, such as fertilizers and pesticides, is essential for economic sustainability. Monitoring and regulating inputs based on crop performance contribute to the cost-effectiveness of production (Robertson *et al.,* 2007).

The residue of wheat, maize, and canola contributes to carbon accumulation in the soil. The speed of decomposition and nutrients release as nitrogen, can impact nutrient availability for subsequent crops. Different agricultural crops have varying effects on the rhizosphere microbiome. Microbe-crop interactions in the rhizosphere can influence nutrient cycling, disease suppression, and overall soil health. Diversity in crop sequences may support beneficial microorganisms, such as mycorrhizal fungi, involved in nutrient uptake (Berendsen *et al.,* 2012).

Crop sequences are designed to optimize water and nutrient usage throughout the agricultural year, selecting crops such as wheat based on their water and nutrient needs during specific growth seasons. Different crop sequences can contribute to overall energy efficiency in agriculture, as diverse crops require different resources (Kasman *et al.,* 2002).

Diverse crop sequences may include crops with varying tolerances to drought or extreme temperatures, enhancing overall resilience to climatic and weather changes. Different crops in agricultural sequences enable the implementation of adaptive strategies to cope with changing climatic and weather conditions, ensuring production stability (Lobell *et al.,* 2010).

Incorporating various crops in crop sequences contributes to agricultural diversity on the farm and potentially supports various insects, birds, and other wildlife. Diverse root systems of these crops assist in water purification and nutrient retention, providing ecosystem services that improve water quality (Kremen *et al.,* 2012).

Integrating these elements in crop sequence management can enhance overall resilience and sustainability in cropping systems. A diverse cropping system, with crops exhibiting different tolerances and growth patterns, can increase resilience against severe weather events, such as heatwaves or heavy rainfall (Thornton *et al.,* 2014).

It appears that the single-crop approach in the cultivation of agricultural crops, without considering the roles of other crops, contradicts the main laws of the production system. This contradiction may manifest in long-term challenges such as yield fluctuations, instability, environmental fragility, and responses to various environmental factors (Veznika, 2019). Some researchers argue that in conservation agricultural systems, the presence of abundant crop residues on the soil surface reduce the efficiency of direct seeding practices, leading to a reduction in crop yield. This hinders the acceptance of these systems by farmers due to significant constraints (Rouzbeh and Khani, 2020).

A three-year study on the combined effects of short-term crop rotations based on wheat and crop seeding in the Karaj region showed that increasing the frequency and diversity of crops in rotation with wheat, especially under direct seeding, can increase wheat yield up to 50%. Adherence to residue management factors within a diverse crop rotation framework and under crop seeding can significantly reduce the consumption of resources such as fuel, water, energy, and herbicides, ultimately enhancing the overall stability and production of wheat (Mehrvar, 2015).

In another study focused on residue management and cropping patterns in agricultural systems in Khuzestan, researchers found that in conservation agricultural systems through minimum tillage with the total crop residue retention, the conservation systems performance did not significantly differ from conventional agricultural systems. However, these conservation systems improved water use efficiency, energy efficiency, and economic benefits (Boqari *et al.,* 2020).

A three-year study on the constraining factors for Conservation Agriculture in Iran identified limited coordination between organizations, inadequate knowledge among relevant stakeholders, inappropriate subsidy policies, and less fertile soils associated with lower economic returns in the initial years of adopting conservation agriculture as the main barriers to its development (Latifi *et al.,* 2016).

To introduce diversity in crop cultivation and production, researchers in the USA encouraged the cultivation of summer cover crops alongside winter wheat and maize, resulting in more than four-crop rotations. This practice led to synergistic effects, contributing to the stability of performance and the overall production system within the applied rotations. The ecological achievements of this diversity, such as weed management through suppressive agricultural approaches, resulted in significant reduction in weed control costs (Anderson, 2008).

Some argue that the performance of the main crop is enhanced after diverse crop types. This improved performance is recognized as the rotation effect (Angus, 2015). Regarding the adaptability of crops and their needs fulfilled by crop rotations and sequences, researchers pointed out goals such as increasing the yield of agricultural crops, producing the required forage for livestock, green manuring to enhance soil fertility, and improving the physical, chemical, and biological soil properties. It seems that these goals in intensive and sustainable agricultural systems need to be precisely considered to make them compatible and provide for the needs of human and animal communities and their production environments (Bomholt and Anderson, 2006).

For the challenges of continuous wheat cultivation in Western Australia, researchers highlighted issues such as soil nutrient depletion, the incidence of root and leaf diseases, increased weed infestation, and other less recognized obstacles in wheat production. They recommended the incorporation of grass companion crops, forage crops, and summer cover crops into the crop rotation system for sustainable wheat production. However, they recognized that the implementation of these measures is not economically feasible in terms of direct costs and anticipated income. Therefore, predicting the response of wheat to companion crops in advance is essential for making rational decisions about the necessity and the best time for introducing companion crops (French et al., 2015).

According to the Lakan and Lundgren report (2018), significant differences exist between conventional maize production systems in the United States, heavily reliant on tillage and external inputs such as fertilizers and pesticides, and conservation agricultural systems prioritizing soil health, biodiversity, and sustainability. The continuation of productivity in most U.S. agricultural soils and large monoculture crops relies on the continuous implementation of

traditional tillage and increasing use of inputs like fertilizers and pesticides, contradicting the resilience and sustainability goals of the agricultural crop production system.

In the regenerative agriculture (RA) model, developed by farmers as a paradigm emphasizing soil health, biodiversity, and profitability, the aim is to produce crops rich in nutrients while preserving ecological stability. Due to limited research on regenerative agricultural methods, quantitative studies comparing their costs and relative benefits to conventional farming methods have been conducted. These studies emphasize the significantly higher ecosystem services and profitability provided to farmers practicing RA compared to conventional models that consume more inputs.

In RA model, pest frequency in conservation farms that avoid pesticide use is considerably lower than in conventional farms using pest control treatments, indicating the effectiveness of preventive and resistance approaches to pests. Regarding maize production and its profitability, while conservation management fields produced 29% less maize, their profitability was 78% higher than conventional maize production systems. This is attributed not to maize yield but to positive correlation between maize profitability and soil organic matter amount in the soil. The concentration of organic matter in the topsoil and the reduction or absence of it in deeper soil layers in conservation agriculture may alter the crop root distribution from vertical to horizontal, contributing to the positive outcomes observed.

Based on these results, we concluded the implementation of agroecological systems requires a shift from conventional to regenerative management systems. However, individual and specific approaches within conservation systems may not necessarily yield positive results. The authors believe that success in both conservation and regenerative management systems requires a cohesive and harmonious combination of approaches in the context of integrated cropping. Achieving balance in the components of food production and environmental preservation can only be expected through the implementation of coordinated and compatible approaches within an integrated cropping system.

Based on the results of this long-term study, the implementation of a wheat/maize-canola/maize crop sequence appears to be economically optimal within the conservation cropping system. It offers several agricultural benefits, such as nutrient cycling, pest and disease management, and overall soil health improvement. This sequence also contributes to achieving long-term resilience and sustainability in the cropping system. The economic viability of this crop sequence, coupled with its compatibility with climatic and soil conditions at the site and the absence of the need for complex direct seeding equipment, makes it cost-effective and a promising approach for small-scale wheat producers dealing with less than 5 hectares of irrigated agricultural land in moderate climates.

According to the statistics from the Ministry of Agriculture, in the agricultural year 2018-19, the production of irrigated and rainfed wheat in Iran was 8.2 and 5.54 million tons, respectively, totaling 13.74 million tons on a combined area of 5.864 million hectares. Irrigated and rainfed wheat grain yield was 4231 and 1409 kilograms per hectare, respectively, compared to the grain yield mean of 2820 kilograms per hectare. The irrigated grains and forage maize production in Iran was 1.1 and 11.64 million tons, respectively, on a combined area of 9.137 and 2.219 million hectares. Irrigated grains and forage maize productivity was 7986 and 53122 kilograms per hectare, respectively. Irrigated and rainfed barley production in Iran was 3.394 and 7.5 million tons, respectively, on a combined area of 0.860 and 3.8 million hectares. The yield of irrigated and rainfed barley was 1916 and 686 kilograms per hectare, respectively. Irrigated and rainfed canola production in Iran was 5.247 and 9.276 million tons, respectively, on a combined area of 4.529 and 7.28 million hectares. The irrigated and rainfed canola seed yield was 8268 and 9655 kilograms per hectare, respectively. In Alborz province, wheat production was 63,675 tons on an area equivalent to 10,978 hectares, representing a 0.78% share in Iran's irrigated wheat production. The irrigated wheat grain yield mean in Iran and Alborz province was 4231 and 5800 kilograms per hectare, respectively, with Alborz province demonstrating a 37% higher grain yield than the national mean for irrigated wheat (Ahmadi et al., 2020).

The objectives of the present research were to investigate the agricultural aspects and irrigated wheat production profitability in crop sequences under conventional and conservation cropping systems, both under normal irrigation and terminal drought conditions. Conservation cropping systems, when consistently compatible with their implementation location and coordinated among their components, provide integrated frameworks for each target area, resulting in improvements in the productivity of wheat, canola, and maize within the system. These improvements include synergies among crops in crop sequences, conservation of the resources, reduced long-term input requirements, integrated weed management, biological, physical, and chemical soil enhancements, improved

crop-soil feedback, enhanced activities of enzyme-microbial hot spots in the rhizosphere, increased organic carbon, reduced soil erosion, and nutrient content improvements in produced crops. Additionally, the absence of pests and diseases and overall soil health improvements contribute to soil remediation, agricultural sustainability, and ecological resilience of the crop production system.

The impact of crop rotation on grain yield and yield components in wheat is a complex interaction influenced by various factors. The sequence of previous crops can affect the soil nutrients availability, disease and pest pressure, and overall soil health. For example, cultivating legumes may increase nitrogen availability for wheat, positively influencing its grain yield. Conversely, continuous cultivation of certain crops in a crop rotation sequence may lead to nutrient imbalance or increased vulnerability to specific pests and diseases, negatively impacting wheat yield components such as grain number and weight.

The goal of successful crop rotation strategies for agricultural crops is to optimize these factors, ensuring an optimal environment for wheat growth and maximizing grain yield. Experimental data indicate that a two-year crop rotation of wheat/maize forage-canola/maize forage results in the highest wheat grain yield in conservation agriculture. To support this choice, various components of wheat yield performance have been considered, and key parameters have been taken into account.

In the study conducted by Lee et al. (2013), the positive impact of selective crop rotation on root growth in wheat was emphasized. Healthy and extensive root systems contribute to better absorption of nutrients and water. Lal and colleagues (2015) reported that the components of maize forage and canola in crop rotation contribute to effective management of crop residues, improving soil structure, water retention, and nutrient cycling. Herr and colleagues (2004) highlighted the role of canola in rotation with wheat due to its potential to enhance soil health, nutrient cycling, and providing a favorable environment for the subsequent growth of wheat.

Cook and West (1991) discussed the benefits of disease and pest control through crop rotation, which can have a positive impact on wheat performance. Hatfield and Dold (2019) demonstrated that appropriate crop rotation sequences optimize water use efficiency in wheat production. Conservation agriculture, including diverse crop rotations and maintaining crop residues on the surface and within the soil, reduces irrigation water consumption in wheat by improving soil conditions with increased organic carbon, soil water retention capacity, and stable soil aggregates, allowing for extended irrigation intervals.

Mendes et al. (2013) focused on the role of diverse crop rotations in enhancing the microbial population in the soil, especially beneficial microbes that increase nutrient availability. The improvement of the microbial function in the rhizosphere is directly related to soil health, enhanced nutrient cycling, increased photosynthesis, and biomass production, ultimately leading to higher wheat grain yield.

In terms of moisture management, Schenkberger et al. (2008) emphasized the impact of crop rotation on soil moisture dynamics, particularly in preserving water during critical growth stages of wheat. Loubet and Geri (2012) demonstrated the resilience against climatic variations and the positive impact of suitable crop rotations in dealing with unfavorable weather conditions, such as drought or excessive rainfall, and their effects on wheat performance.

Additionally, Hatfield et al. (2011) showed how crops within crop rotations can synchronize and complement each other in phenological stages and physiological processes, maximizing the overall efficiency of the selected crop rotation. Power (1992) highlighted the importance of weed management through an appropriate crop rotation sequence, reducing competition for resources and increasing wheat grain yield.

Hobbs and Govaerts (2010) discussed the synergy of conservation agriculture with suitable crop rotations and their significance in sustainable agriculture. Regarding the decomposition of crop residues and the sequestration of soil organic carbon, Lal et al. (2005) emphasized the positive effects of preserving maize forage and canola residues on soil organic matter, soil improvement, water retention, and nutrient availability.

Diverse crop rotations contribute to agricultural diversity and improve ecosystem services, such as increased pollination or natural pest control (Power, 2010). Alavi (2009) highlighted the positive role of crop rotations in making

essential nutrients available for wheat growth and performance. "Wartz et al. (2006) reported positive impacts of diverse crop rotations on diversity and activity of the soil microbes, specifically on microbes associated with nutrient cycling and crop growth."

Farooq et al. (2012) discussed drought tolerance and water use efficiency in canola and its positive effect on wheat grain yield when grown after canola. Logtenberg et al. (2009) reported the positive role of growth-promoting substances produced by soil bacteria within crop rotations in enhancing crop access to nutrients and their resistance to crop diseases.

Chen et al. (2004) emphasized the positive role of suitable crop rotations in soil improvement with organic inputs throughout crop sequences and their effects on fertility and soil structure. Crop rotations can influence soil nutrient levels and the availability of nutrients, impacting wheat grain yield components. For example, increasing soil nitrogen levels can positively influence wheat spike growth and grain filling (Malarino et al., 2002).

Crop rotations may affect the prevalence of specific diseases and pests. A well-designed crop rotation sequence may reduce the risk of exposure to diseases and vector-transmitted diseases, leading to healthier wheat and better grain yield components (Zhang et al., 2019). Decomposition of previous crop residues in crop rotations can impact soil organic matter, microbial activity, and nutrient cycling, influencing wheat grain yield components such as the number of the spikes and grain weight (Wang et al., 2016).

Crop rotations optimizing water use efficiency may also have a positive impact on wheat grain yield components. Plants with different water requirements can assist in managing water availability, influencing aspects such as spikelet number and grain size (Daryanto et al., 2017).

The common practice of double cropping in South Asia's rice-based farming systems, including rice-rice, rice-wheat, and rice-corn rotations, emphasizes approximately 75% of the net cultivated area. In these systems, the replacement of fallow cycles during the dry season with mixed cropping of crops such as mung bean, oilseed mustard, and jute is recommended. Moreover, emphasis is placed on low tillage, avoiding complete residue removal, or burning, as their implementation negatively affects soil quality and health, leading to soil acidification and carbon loss. Overall, implementing conservation agricultural systems has been introduced as a resource-saving technology that enhances crop establishment, reduces water and energy consumption, lowers production costs, increases income, and improves soil quality (Kropenicki et al., 2015; Ershadullah et al., 2023; Preeti et al., 2018; FAO, 2011; Dixon et al., 2020; Gatala et al., 2020).

Changes in crop sequences in rainfed areas have been well-recognized for increasing the yield of cereals like wheat. Kerkgaard et al. (2008) compiled texts from around the world and demonstrated the benefits of increasing wheat grain yield by up to 20% or more. Regarding the key mechanisms responsible for these benefits, including effects on disease suppression, improved nitrogen nutrition, and water supply, there is abundant information. However, researchers are still challenged by the "effects of crop rotation" that are not well-documented or fully understood. They summarized the better-known crop rotation mechanisms and discussed other mechanisms (such as changes in rhizosphere biology, allelopathy, or soil structure) that may contribute to a complete understanding of the observed benefits of rotation in agriculture. For over 2000 years, producers have emphasized the implementation of new techniques used to examine these less understood aspects of the "rotation effect." On a farm level, the inability to invest in the benefits of companion crops may be more related to economics, suitable companion crop availability, and crop response complexity. Computer-based decision support tools have been developed to help farmers utilize information collected from scientific studies, although efforts to integrate this information at the whole-farm scale are in the early stages.

The grain yield mean wheat response to broadleaf companion crops in comparison to continuous wheat cropping is surprisingly consistent over large regions and time scales, although there is significant variability in the response of each crop depending on location, climatic conditions, and other crops. Considering various aspects of cropping in northern Europe, the mean performance response is about 20%, but in individual studies, it varies from 7% to 57% (Prew et al., 1986; McEwen et al., 1989; Christen et al., 1992; Sieling et al., 2004). A 26 experiments dataset in southern Australia showed that the wheat grain yield mean benefit after canola was 20% with the range of 16% to 197% (Angus et al., 2001). For various regions of North America, the wheat grain yield mean with preceding

companion crops is also diminished by approximately 20% (Eshun et al., 2002; Kropinski et al., 2002; Miller et al., 2002, 2003; Smiley et al., 1994, 1996; Soon and Clayton, 2002), although the responses may vary from 10% to 62% (Cook et al., 2002; Stevenson and vanKessel, 1996). Responses are significantly less dependable in semi-arid regions, exhibiting a tendency towards lower levels of reliability (Gan et al., 2003; Zentner et al., 2001). Moreover, the outcomes may potentially take a negative turn in instances where companion crops are substituted. Performance benefits may be associated with an increase in grain protein concentration (Evans et al., 2003; Kirkegaard et al., 2008) and could persist in the cultivation of the second cereal (Kirkegaard et al., 1997; Evans et al., 2003) or potentially be lower (Harris et al., 2002).

In some studies, the hidden mechanisms of these performance responses are clear, along with their interaction with other management methods, while in others, a significant portion of the crop response cannot be explained by commonly measured variables (such as disease, nitrogen, and water), leading to speculation about the nature of the "rotation effect."

With the increasing global demand for food, it is essential to develop and adopt sustainable methods that not only increase efficiency but also preserve natural resources. This research aims to explore the multifaceted dynamics of irrigated wheat production in Alborz province, delving into the complex interaction between agriculture and the economy. By focusing on different crop rotations under conventional and conservation farming systems, the study seeks to uncover the intricate relationships between farm management strategies, wheat performance, resource use efficiency, and economic returns. The findings of this research are intended to contribute valuable insights to enhance sustainable wheat production in the temperate cold climate of Alborz province.

Materials and methods

This experiment was conducted using a split-strip plot statistical design within completely randomized blocks, where conventional agricultural and CA-based management systems (direct planting) were assigned to main plots, one-year and two-year crop sequences to horizontal plots, and normal irrigation and irrigation cessation to vertical plots during the agricultural years of 1392-1397 in four replications at the research farm of the Institute of Plant Breeding and Seed Preparation in Karaj County, Alborz Province. The experiment comprised 24 treatments, including 12 treatments related to conventional management treatments (T) with normal irrigation (I) and drought stress irrigation (D) methods, and one-year and two-year wheat/maize crop sequences as controls (WM), two-year crop sequences of wheat/lucerne/maize (WCM), two-year crop sequences of wheat/lucerne-canola/maize (WCKM), two-year crop sequences of wheat/maize-canola/maize (WMKM), two-year crop sequences of wheat/maize-canola/lucerne (WMKC), and two-year crop sequences of wheat/lucerne-wheat/maize (WCWM). The other 12 treatments were related to CA-based management treatments (C) with normal irrigation (I) and drought stress irrigation (D) methods, and one-year and two-year wheat/maize crop sequences as controls (WM), two-year crop sequences of wheat/lucerne/maize (WCM), two-year crop sequences of wheat/lucerne-canola/maize (WCKM), two-year crop sequences of wheat/maize-canola/maize (WMKM), two-year crop sequences of wheat/maize-canola/lucerne (WMKC), and two-year crop sequences of wheat/lucerne-wheat/maize (WCWM). In conventional management, wheat varieties, forage maize, lucerne, and canola were Parsi, 704, Karaj lucerne, and Zarfam, respectively. Parsi wheat seeds were sown at a seed density of 400 seeds per square meter using conventional linear practices and direct sowing. The seed rates for maize, canola, and wheat in conventional management were 20, 25, 8, and 200 kilograms per hectare, respectively, while in CA-based management, 10 to 20 percent more than the recommended rates in conventional management were considered.

In order to chemically control weeds in CA-based management in wheat, Grains Star and Puma Super herbicides were used to control broadleaf and narrow-leaf weeds, respectively. In canola, Gallant herbicide was used to control narrow-leaf weeds, while in maize, Nicosulfuron herbicide was used to control both broadleaf and narrow-leaf weeds, and Glyphosate systemic herbicide was used outside the cropping season, two weeks before wheat planting, to control all broadleaf and narrow-leaf weeds. Regarding lucerne, due to its multi-cut nature, after the first cut along with weeds, the weed pressure significantly decreased in the second cut, and there was no need for any herbicide application. It is worth mentioning that in the CA-based cropping system, due to the dominance of weeds such as wild oat and couch grass in the first and second years of this study, which originally continued to the fifth and sixth years of implementation of CA-based agricultural practices in direct seeding format (from the previous project), herbicide usage increased. However, it was unable to completely control weeds, leading to yield losses in some experimental

treatments in the sixth and seventh agricultural years. Wheat grain yield notably decreased in the seventh year. Therefore, it was decided to modify the CA-based cropping system to shallow, non-inversion, and reduced tillage along with double shallow tillage, using a light disc harrow for crops within crop sequences until the ninth agricultural year. The consequence was sufficient weed control and a significant increase in wheat grain yield in experimental treatments, although wheat grain yield was significantly better in the conventional management system (Figure 1). A declining trend in wheat grain yield in the first five years of the experiment under the CA-based cropping system was observed in accordance with the data from the agricultural years 94-93 and 95-94 onwards after the implementation of this experiment (Peterson et al., 2001).

The economic analysis of this research was conducted using partial budgeting technique with the assistance of relevant statistical software. In the partial budgeting method, first, the costs and incomes of treatments were estimated, and then the net present value of activities was calculated. Net income is the difference between gross value and production costs of the produced commodity, and the benefit-cost ratio is the ratio of the present value of the gross value of the produced commodity to the present value of the production costs. If this ratio is greater than one, the activity is economically justified. The analysis of the economic and non-economic hypothesis of replacing treatments in the partial budgeting method indicates how the income and costs of treatments would change if other treatments were replaced instead of the superior treatment.

$$(1) \qquad NI_v = GI_v - TC_v$$

So that: The profit derived from cultivating the variety in treatment in year tt, PtPt, and the respective gross value and production cost of the cultivated variety vv in treatment in year tt, are as follows.

In this study, in order to standardize the data, the one-time payment formula in engineering economics was used, and the following equations were used to determine the net present value (NPV) and the benefit-cost ratio (BCR) (Soltani, 2007).

$$(2) \qquad F = P(1+r)^t$$

$$(3) \qquad NPV = \sum_{t=1}^{T} \left(\frac{GI_{vt} - TC_{vt}}{(1+r)^t} \right)$$

$$(4) \qquad R = \left(\sum_{t=1}^{T} GI_{vt}/(1+r)^t \right) / \left(\sum_{t=1}^{T} TC_{vt}/(1+r)^t \right)$$

Such that: The future value of cultivating the variety in treatment in year tt, the current value of the cultivated variety v in treatment in year t, the conversion coefficient (1+r)n(1+r)n, analysis years tt, where rr represents the bank discount rate.

The research farm of the Institute of Plant Breeding and Seed Preparation in Karaj has a geographic position of 50 degrees and 93 minutes east longitude and 35 degrees and 79 minutes north latitude, at an elevation of 1321 meters above sea level, with an annual rainfall of 250 millimeters in loamy alluvial soil texture. In the conventional cropping system, the stages from pre-planting to harvesting adhere to the practices of the region's farmers, while in conservation agriculture, important practices such as minimum tillage or reduced tillage, non-inversion tillage using minimal tillage equipment, preparing seedbeds, planting seeds, not burning crop residues, retaining at least 30 percent of residues on the soil surface, and reducing pesticide use are considered. The hypotheses of this study include that conservation agriculture is more economically viable than conventional management. Additionally, the most profitable crop sequence is wheat/maize-canola/maize in the conservation farm.

Results and Discussion

Agricultural Results

According to Table 1, in the first rotation cycle, the cropping system effect on traits such as thousand kernel weight, grain yield, and wheat harvest index was significant at a one percent level of probability. Therefore, it can be concluded that implementing a CA-based cropping system leads to increase in thousand kernel weight due to the improvement in wheat grain growth conditions during grain filling cycle, resulting in increased grain yield and harvest index. Regarding the crop rotation factor, the results indicate that this factor can only affect grain yield due to the balanced environment provided by diverse crop rotations, leading to increased wheat grain yield. Concerning the interaction of the two factors, cropping system (conventional and CA-based) and crop sequence, the results show significant difference only in terms of grain yield, indicating that due to differences in components, conventional and CA-based cropping systems have different effects on grain yield. Thus, appropriate crop rotation recommendations should be made separately for each of them. Additionally, regarding the main crop type factor on wheat traits, this factor had significant effect on all measured traits ($p<0.01$). The interaction of irrigation by main crop type was only significant for the thousand kernel weight trait ($p<0.05$), indicating that increasing thousand kernel weight requires attention to the main crop type and proper irrigation management. According to Table 2, during the second rotation cycle, the cropping system effect on traits of spikes number per square meter, thousand kernel weight, grain yield, and harvest index were significant ($p<0.01$). Whereas, the crop rotation effect was only significant on wheat grain yield ($p<0.01$), indicating the interaction of the cropping system by crop rotation was significant on wheat grain yield ($p<0.05$). Furthermore, irrigation effect on traits of thousand kernel weight, biomass, and harvest index were significant ($p<0.05$), while their effect on wheat grain yield was also significant ($p<0.01$). Main crop type effects on spikes number per square meter, biomass, and harvest index were significant ($p<0.05$), while its effect on wheat grain yield was also significant ($p<0.01$). The interaction of the cropping system by irrigation on the thousand kernel weight trait was significant ($p<0.05$). Crop sequence by irrigation interaction on wheat grain yield was significant ($p<0.01$), and the interaction of the cropping system by main crop type on the harvest index was significant ($p<0.05$). Moreover, the simple effects of the irrigation and the main crop type on spikes number per square meter were significant ($p<0.05$). Finally, the results showed that cropping system interaction by crop sequence by irrigation by main crop type was significant ($p<0.01$), indicating that recommendations for increasing wheat grain yield depend on environmental factors, namely conventional and CA-based cropping systems, crop sequences, irrigation managements and crop types (wheat or canola), which should be analyzed separately and implemented systematically to get them sustainably combined.

In summary, compared to the control treatment (wheat/corn forage), the wheat grain yield in the crop sequences of the agricultural year 93-92 (start of the first cycle) was higher in the second, third, and fifth treatments than in the control treatment. In the agricultural year 94-93, the wheat grain yield in the sixth treatment was lower than the control treatment. Based on the two-year Mean of the first cycle (93-92 and 94-93), the wheat grain yield was only higher in the third treatment (wheat/clover-barley-rape/corn forage) compared to the control treatment. In the agricultural year 95-94 (start of the second cycle), the wheat grain yield of none of the treatments from second to sixth exceeded that of the control treatment. In the agricultural year 96-95, the wheat grain yield in the third, fourth, and fifth treatments was higher than the control treatment. Based on the two-year Mean of 95-94 and 96-95 (second cycle), the wheat grain yield of the second to sixth treatments exceeded that of the control treatment. In summary, the third treatment had the highest wheat grain yield with 4089 and 6368 kilograms per hectare in the first and second cycles respectively, compared to the control treatment (with wheat grain yield of 2697 and 5825 kilograms per hectare respectively), while the wheat/corn-rape/corn treatment only showed superiority in the second cycle with a wheat grain yield of 6242 kilograms per hectare over the control treatment (5825 kilograms per hectare). Based on the Mean yields of the two cycles, the third and fifth treatments showed superiority over the control treatment, with the highest wheat grain yield belonging to the third treatment. Therefore, the third treatment (wheat/clover-barley/rape/corn forage) is recognized as the best crop sequence in terms of performance and agricultural diversity, while the fourth treatment (wheat/corn forage-rape/corn forage) ranked next.

Aghel and colleagues (2023) demonstrated that in compact rice-based agricultural systems, particularly in conservation agricultural management systems, they could have a positive impact on the performance of winter crops. In this study, the conservation management system, compared to the conventional management system, achieved improvements in rice equivalent yield and increased efficiency and profitability of compact agricultural systems. The results of this three-year study indicated that although rice yield in the conservation system was about 8% lower than

the conventional system, the performance of winter crops was approximately 13% higher in the conservation system compared to the conventional system. Additionally, implementing the conservation system led to increases of approximately 5%, 3%, and 6% in rice equivalent yield, calories, and protein yield respectively, compared to the conventional system. Moreover, implementing alternating soil management led to an approximate but significant 1% improvement in winter crop performance. The increased efficiency in conservation and alternating soil management systems resulted in obtaining 16% more gross margin. Furthermore, in the conservation system, there was a reduction in labor costs and total production costs compared to conventional system. Regarding different crop sequences, the rice-maize sequence had the best rice equivalent yield, calories, protein yield, and gross margin percentages, which were 24%, 26%, 66%, and 148% respectively higher than the rice-rice crop sequence. Additionally, the rice-wheat-mung bean sequence had the highest rice equivalent yield by 30% and ranked second in terms of gross margin percentage by 118%. In light of these results, this study demonstrated that the use of conservation agricultural management systems in conjunction with diverse crop sequences could significantly enhance the performance of winter crops and bring about notable improvements in rice equivalent yield, calories, protein yield, and gross margin. The findings of this research are consistent with those of Aghel and colleagues (2023) and emphasize the importance of implementing a diverse wheat/corn forage-canola/corn forage crop sequence within the framework of conservation agricultural management systems.

Conservation Agriculture (CA) and resource conservation management practices, such as direct seeding or minimum tillage, maintaining crop residues, diversification of rotations and crop sequences, are widely supported due to their ability to reduce the use of non-renewable resources, reverse soil degradation, restore soil fertility, decrease greenhouse gas emissions, promote biodiversity and ecosystem services, conserve water, provide economic benefits for farmers, and increase resilience to climate change. In summary, adopting conservation and resource-efficient agricultural methods to create more sustainable and resilient agricultural management systems is essential for addressing environmental concerns, ensuring long-term productivity and agricultural sustainability. The operationalization of conservation agriculture in irrigated farmlands requires the provision of integrated agricultural packages consisting of mutually compatible agricultural practices across components and environments (weather and climate in different time cycles) that are resilient and sustainable. This research, by creating a logical combination of environmentally compatible management approaches, has provided conditions for moving towards achieving a compromise between economic production and minimizing dependency on inputs, with minimal pressure on resources, and achieving this through continuous implementation of these management practices over successive years.

Adding microbes to the soil can have several beneficial effects on soil health, plant growth, and overall ecosystem performance. Microbes, including bacteria, fungi, and other microorganisms, play important roles in various soil processes. They are essential for decomposing organic matter and releasing nutrients in a form that plants can absorb. They play a key role in nutrient cycling, making essential elements such as nitrogen, phosphorus, and potassium more available to plants. Certain microbial species produce substances that help improve soil structure, leading to better water retention, aeration, and drainage, creating a more favorable environment for plant roots. Beneficial microbes can compete with harmful pathogens in the soil and suppress their growth. Some microbes produce antibiotics or other compounds that prevent plant diseases and aid in plant protection. Certain microbes establish symbiotic relationships with plants, such as mycorrhizal fungi, which can enhance nutrient uptake by plant roots, leading to increased growth, vigor, and overall plant health.

Some soil microbes act as natural enemies of soil-borne pests. They can prey on or parasitize harmful organisms and help control pest populations in the soil. Improving soil structure through microbial activity can reduce the risk of soil erosion. The binding agents produced by microbes help hold soil particles together, preventing them from being easily washed away by water. Microbes are essential for decomposing organic matter, breaking down dead plant and animal materials into humus. This process aids in nutrient recycling and contributes to the formation of carbon-rich, organic soil. Some microbes are capable to decompose or detoxify pollutants present in the soil, a process known as bioremediation, which can help clean up contaminated soils.

When introducing microbes to the soil, it's crucial to take into account the unique requirements of both the soil and the plants, in addition to the types of microbes being added. Different microbes perform different functions, and their effectiveness can be influenced by environmental factors such as soil pH, moisture levels, and temperature.

Additionally, some microbes may naturally exist in the soil, while others may need to be introduced through soil amendments or inoculants.

Microbial participation in the nutrient cycle is well documented. Bacteria, fungi, and other microorganisms decompose organic matter and release essential nutrients. For example, mycorrhizal fungi establish symbiotic relationships with plant roots and aid in nutrient uptake (Smith & Read, 2008). The accumulation and improvement of soil structure by microbes have been widely studied. Extracellular polymeric substances (EPS) produced by microbes significantly contribute to soil aggregation (Chenu, 1993). Conflicting interactions of beneficial microbes with soil-borne pathogens have been noted. This includes the production of antibiotics and lytic enzymes by specific microbes to inhibit pathogen growth (Raaijmakers et al., 2009). Research has demonstrated that mycorrhizal fungi enhance nutrient absorption and promote plant growth (Smith & Read, 2008). Beneficial microbes, including pathogenic fungi and nematodes, aid in the biological control of soil-borne pests (Leiss, 2012). Microbial activities that improve soil structure can reduce soil erosion. EPS produced by microbes act as binding agents and stabilize soil aggregates (Six et al., 2004).

Microbial decomposition is a fundamental process in soil ecology. Different microbial communities play roles in decomposing organic matter and in humus formation (Bardgett & van der Putten, 2014). Certain microbes exhibit the capacity to degrade soil contaminants; for instance, bacteria adept at breaking down hydrocarbons have been employed in the remediation of oil spills (Margesin et al., 2007).

The fundamental question is whether adding microbes through introducing new plants into crop rotations may be possible. The specific plant composition in a crop rotation can influence soil microbial populations. Different plants emit unique root exudates and residues, providing a diverse array of organic matter for soil microbes.

Crop rotation or plant diversification within a crop sequence can have multiple effects on soil microbial population and activity.

Crops exhibit diverse nutrient demands and absorption behaviors, reflecting their unique metabolic processes and growth characteristics. Crop rotation can influence the nutrient cycle in the soil, as microbes respond to changes in nutrient inputs from different plants (Drinkwater et al., 1998). Some crops form beneficial mycorrhizal associations with fungi, and crop rotations with different mycorrhizal preferences can increase overall soil mycorrhizal diversity (van der Heijden et al., 2008). Some crops, especially those with deep root systems, can improve soil structure. Root growth can increase soil aggregation and aeration and provide a habitat for beneficial microbial communities (Gupta et al., 2015).

Crop rotation impact on soil microbes is context-dependent and relies on various factors such as climate, soil composition, and agricultural practices. Moreover, microbial reactions can be diverse, and not all alterations may yield favorable outcomes. Sustainable agricultural approaches are typically tailored to leverage these microbial dynamics for enhanced soil fertility and crop yield, with conservation agriculture systems offering particularly conducive environments, especially when integrated into cover crop systems, as highlighted by Mehrotra et al. (2023).

Applying terminal drought only to wheat, while other crops receive full irrigation in crop sequence (canola and forage corn), introduces significant dynamics to the agricultural ecosystem. Imposing Terminal dryness on wheat may lead to changes in the microbial population composition in the rhizosphere and surrounding soil. Drought-resistant or stress-tolerant microbes may become dominant, while other microbes sensitive to dry conditions may decrease abundantly. Wheat under water stress may alter its root exudation patterns. This can impact the available carbon sources for soil microbes. Contrasting conditions between irrigated and drought-endured crops may lead to different microbial reactions in hot spots of the rhizosphere. Terminal dryness in wheat may affect soil structure and aggregate formation in that specific region. While conservation agricultural practices contribute to overall soil health, localized changes in soil conditions due to Terminal drought stress in wheat may affect rhizosphere habitat and microbial activity. Drought stress on wheat can influence the soil nutrient cycle. Microbial activities involved in nutrient transformations may be affected and potentially impact nutrient availability for subsequent crops in the crop sequence. Water-demanding crops (such as forage corn, canola) may assist in maintaining a more stable and diverse microbial population, acting as a shield against potential negative effects of Terminal drought stress on wheat. Overall resilience of soil microbial populations to these changes depends on factors such as duration and intensity of drought. Dry

conditions on wheat may lead to faster decomposition of wheat residues and affect the organic matter cycle in that specific area. Irrigated plant residues may decompose at different rates, contributing to spatial heterogeneity in soil microbial activity. Monitoring soil microbial diversity, enzymatic activities, and nutrient levels in both irrigated and non-irrigated farm sections can provide valuable insights into short-term and long-term effects of this agricultural management strategy on soil health and microbial populations. Additionally, studying the performance of subsequent crops in the crop sequence under these conditions can aid in evaluating the overall sustainability of the chosen approach.

Table 1 Analysis of variance for Parsi wheat traits under farming management treatments, crop sequences, irrigation methods, and main crop types in the first rotation cycle.

SOV	DF	Grain yield	Biological yield	Harvest index (%)	Spikes number per square meter	Thousand Grain Weight
Replicate (block)	3	14241779.4	212581856.8 ^{ns}	857.88 ^{ns}	150405.5 ^{ns}	192.43
Crop management system	1	49770023.5**	86714880.3 ^{ns}	2489.6**	158930.1 ^{ns}	346.9**
Replicate x Crop management system	3	13691918.9	253627190.2 ^{ns}	260.549 ^{ns}	178625.4 ^{ns}	190.6 ^{ns}
Crop sequence	5	10633534.9**	139770428.4 ^{ns}	389.189 ^{ns}	596584.73 ^{ns}	231.796 ^{ns}
Crop management system x Crop sequence	5	28812663.7**	378244607.7 ^{ns}	1428.938 ^{ns}	294246.98 ^{ns}	88.080 ^{ns}
Replicate x Crop sequence	15	17788077.8 ^{ns}	460936005.8 ^{ns}	3612.743 ^{ns}	749035.9 ^{ns}	514.45 ^{ns}
Irrigation method	1	3635502.1*	8550564.2 ^{ns}	38.511 ^{ns}	25162.5 ^{ns}	0.323 ^{ns}
Crop type	1	17360493.5**	426593025.3**	5001.8645**	1525107.0**	290.34**
Crop management system x Irrigation method	1	1998384.1 ^{ns}	7495521.3 ^{ns}	88.299 ^{ns}	54203.5 ^{ns}	20.804 ^{ns}
Crop sequence x Irrigation method	5	3665744.2 ^{ns}	134821884.2 ^{ns}	657.104 ^{ns}	379805.5 ^{ns}	116.22 ^{ns}
Crop management system x Crop type	1	768361.02 ^{ns}	5075851.7 ^{ns}	25.93 ^{ns}	23763.0 ^{ns}	49.863 ^{ns}
Irrigation method x Crop type	1	137388.0 ^{ns}	2447130.1 ^{ns}	101.028 ^{ns}	15.19 ^{ns}	133.579*
Crop sequence x Crop type	5	2192100.8 ^{ns}	47143264.2 ^{ns}	1096.231 ^{ns}	173428.44 ^{ns}	276.214 ^{ns}
Crop management system x Crop sequence x Irrigation method	5	2271770.6 ^{ns}	51171650.5 ^{ns}	484.367 ^{ns}	57687.5 ^{ns}	208.184 ^{ns}
Crop sequence x Irrigation method x Crop type	5	2169493.5 ^{ns}	56569020.5 ^{ns}	785.496 ^{ns}	389113.0 ^{ns}	180.616 ^{ns}
Crop management system x Irrigation method x Crop type	1	43440.3 ^{ns}	60025423.5 ^{ns}	467.814 ^{ns}	167915.02 ^{ns}	41.002 ^{ns}
Crop management system x Crop sequence x Irrigation method x Crop type	5	4820575.5 ^{ns}	339757685.9 ^{ns}	1803.269 ^{ns}	547185.1 ^{ns}	249.254^{ns}
Replicate x Irrigation method	3	1720485.4 ^{ns}	105446912.6 ^{ns}	253.471 ^{ns}	53331.3 ^{ns}	71.312 ^{ns}
CV%		25.52	27.90	29.72	23.82	26.05

"Significant at the five percent and one percent levels, respectively. ns: Not significant."

Table 2: Analysis of variance for Parsi wheat traits under the influence of agronomic management treatments, crop sequences, irrigation methods, and main plant types in the second crop rotation period.

SOV	DF	Grain yield	Biological yield	Harvest index (%)	Spikes number per square meter	Thousand Grain Weight
Replicate (block)	3	8735409.5 ^{ns}	86168448.3 ^{ns}	106.17 ^{ns}	17561.8 ^{ns}	22.297 ^{ns}
Crop management system	1	7951695.02**	27599262.2 ^{ns}	1048.14**	915131.4**	10075.14**
Replicate x Crop management system	3	472889.9 ^{ns}	216802871.6 ^{ns}	430.92 ^{ns}	3335.05^{ns}	148.92 ^{ns}
Crop sequence	5	6471300.02**	557635.6 ^{ns}	1.89 ^{ns}	11315.64 ^{ns}	112.891^{ns}
Crop management system x Crop sequence	5	4232791.9*	7761796.0 ^{ns}	17.01 ^{ns}	50.766 ^{ns}	213.89 ^{ns}
Replicate x Crop sequence	15	2717797.67 ^{ns}	26417682.6 ^{ns}	219.42 ^{ns}	23114.797 ^{ns}	233.92 ^{ns}
Irrigation method	1	12880023.8**	107858610.3*	1.266 ^{ns}	582.02^{ns}	643.89*
Crop type	1	84472183.3**	113353285.6*	558.14*	116025.39*	356.266 ^{ns}
Crop management system x Irrigation method	1	28518.8 ^{ns}	487553.1 ^{ns}	319.516 ^{ns}	6621.89 ^{ns}	892.516*
Crop sequence x Irrigation method	5	102480.02**	24113010.3 ^{ns}	118.266 ^{ns}	6142.64 ^{ns}	0.016 ^{ns}
Crop management system x Crop type	1	478691.02 ^{ns}	23275800.3 ^{ns}	467.641*	25560.02 ^{ns}	23.766 ^{ns}
Irrigation method x Crop type	1	183505.1 ^{ns}	58913300.3 ^{ns}	135.141^{ns}	54230.77*	62.016^{ns}
Crop sequence x Crop type	5	14890916.3 ^{ns}	28694770.6 ^{ns}	9.766^{ns}	37781.64 ^{ns}	467.64 ^{ns}
Crop management system x Crop sequence x Irrigation method	5	954773.3^{ns}	3826914.1 ^{ns}	236.391 ^{ns}	4438.89 ^{ns}	15.016^{ns}
Crop sequence x Irrigation method x Crop type	5	57540.02 ^{ns}	877969.0 ^{ns}	62.016^{ns}	2081.64*	0.391 ^{ns}
Crop management system x Irrigation method x Crop type	1	649434.5 ^{ns}	16114203.1 ^{ns}	31.641 ^{ns}	65088.77 ^{ns}	4.516 ^{ns}
Crop management system x Crop sequence x Irrigation method x Crop type	5	12115099.4**	11203318.8 ^{ns}	107.781 ^{ns}	8067.91 ^{ns}	288.031 ^{ns}
Irrigation * Replicate method	3	3213159.2 ^{ns}	123834700.6 ^{ns}	260.547 ^{ns}	19903.17 ^{ns}	591.672 ^{ns}
CV%		20.42	20.00	21.70	15.59	22.56

"Significant at the five percent and one percent levels, respectively. ns: Not significant."

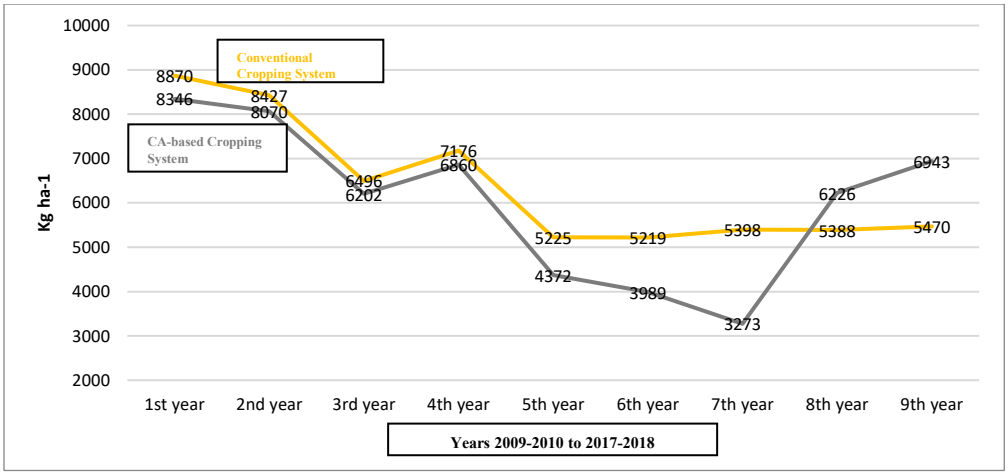


Figure 1 depicts the trend of changes in wheat grain yield under conventional and CA-based agricultural systems during the nine agricultural years from 88-89 to 96-97.

According to the results in Figure 1, in the first agricultural year (2009-2010) as the base year, the results indicate the superiority of wheat grain yield under the conventional farming system compared to the wheat under the conservation agricultural management. This superiority in grain yield can be attributed to the immediate effects of soil inversion by plowing on conventional farming and the implementation of no-tillage and direct drilling of wheat with non-inversion soil tillage as conservation practices. In the second agricultural year (2010-2011), wheat grain yield in both conventional and conservation managements was slightly lower than the base year. In the third agricultural year (2011-2012), a significant decline in wheat grain yield was observed, with the decline slightly less in the conservation management compared to the conventional management. The reason could be due to the factors as increased soil density and its compaction, as well as yearly weather conditions during the project implementation. In the fourth agricultural year (2012-2013), wheat grain yield increased, which could be related to transitions from conventional to conservation managements, changes from crop residue removal to residue burning in conventional farming, or keeping of residue in conservation management. In the fifth agricultural year (2013-2014), the increasing trend in wheat grain yield in both conventional and conservation managements reversed compared to the fourth agricultural year, with a significant decrease in grain yield observed in the conservation system. From the sixth to the ninth agricultural years (2014-2017), wheat grain yield showed a relatively uniform trend with minor fluctuations. However, wheat grain yield in the conservation management declined until the seventh agricultural year (2015-2016), reaching its highest level in a nine-year trend, but in the eighth and ninth years (2017-2018), due to the changes in soil management implementations of double-minimum tillage for Summer and Fall seed bed preparations as non-inversion shallow-depth vertical tillage completed with the raised bed planting system, the wheat grain yield showed increasing trend in the conservation management. In fact, in the irrigated wheat cropping system in the moderate cold climate region at Karaj, it is not advisable to engage in direct drilling of this crop in the cool autumn season unless limited to post-harvest wheat planting for summer crop cultivation, while conventional tillage is implemented, which contradicts the spirit of implementing conservation agriculture in a long-term agricultural management system. While achieving accurate and logical results from implementing conservation agriculture in wheat farming is the goal in any location so that all elements of conservation agriculture are considered, and only under such conditions can the operational success of conservation agriculture be guaranteed. Additionally, according to the results, no significant difference in wheat grain yield was observed between the conventional and conservation systems, but the wheat grain yield mean during the five-year cycle (97-92) of implementation in the conservation management (5199 kg/ha) was approximately 5.2% higher than in the conventional management (4942 kg/ha) (Table 3). The wheat grain yield mean during the experiment (1392-96) in the wheat/berseem clover-canola/forage maize rotation (WCKM) was the highest at 5608 kg/ha, which was 16.7% higher compared to the observed rotation (wheat/corn (WM)) with grain yield of 4803 kg/ha, and also to the other crop rotations including (wheat-berseem clover-forage maize (WCM), wheat/corn-canola/corn (WMKM), wheat/forage corn-canola/berseem clover (WMKC), and wheat/berseem clover-wheat/corn (WCWM) with lower grain yields of 23.6%, 25.8%, 13.6%, and 25.9%, respectively (Table 4).

Table 3: Parsi wheat grain yield means in conventional and conservation agricultural managements (Kg ha^{-1}).

Agricultural Management	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	Mean
Conventional agricultural management (T)	2859	5206	4904	6274	5470	4943
Conservation agricultural management (C)	2380	4317	5666	6692	6943	5200

Table 4: Wheat grain yield means in varied crop sequences (Kg ha^{-1})

Crop sequence	2013-2014	2014-2015	1st crop rotation cycle means	2015-2016	2016-2017	2nd crop rotation cycle means	All crop rotation cycles means
CS1 -WM	**2697**	**4868**	**3783**	**5484**	**6166**	**5825**	**4804**
CS2 - WCM	**3130**	-	**3130**	-	**5948**	**5948**	**4539**
CS3- WCKM	**4089**	-	**4089**	**5402**	**7334**	**6368**	**5608**
CS4- WMKM	**2675**	-	**2675**	-	**6242**	**6242**	**4459**
CS5 - WMKC	**2748**	-	**2748**	**4969**	**7099**	**6034**	**4939**
CS6 - WCWM	**2599**	**4655**	**3627**	-	**6108**	**6108**	**4454**

Table 5: Wheat grain yield means in agricultural managements, crop sequences, and irrigation methods

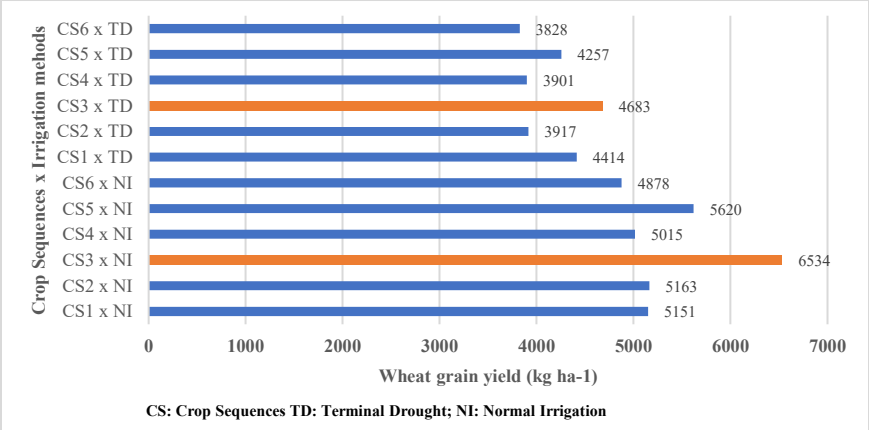
	Agricultural year				
	2013-14	**2014-15**	**2015-16**	**2016-17**	**2017-18**
Agricultural management					
Conventional	2859a	5206a	4904a	6274a	5470b
Conservational	2380b	4317b	5666b	6692a	6943a
Crop sequence					
CS1 -WM	2697bc	4868a	5484a	6166b	
CS2 - WCM	3130b			5948b	
CS3- WCKM	4089a		5402a	7334a	
CS4- WMKM	2675bc			6242b	
CS5 - WMKC	2748bc		4969ab	7099a	
CS6 - WCWM	2599bc	4655a		6108b	
Irrigation Method					
Normal irrigation	3122a	5033a	5808a	7645a	6715a
Terminal drought	2857a	4489a	4862b	5321b	5697b
		LSD5% 522.1 Kg ha^{-1}			LSD5% 621 Kg ha^{-1}

Based on the results of Table 5, the four-year Mean wheat grain yield in the second to fifth cropping years compared to the first cropping year (baseline year) under conventional and conservation agronomic managements showed an increase of 22.9% and 33.6%, respectively, indicating the positive effects of implementing conservation management and its superiority over conventional management. This increase regarding the treatments of irrigation methods, including normal irrigation and late-season drought stress, were 24% and 20.5%, respectively, suggesting that part of this difference might be attributed to the implementation of principles of conservation agronomic management, which provided conditions to alleviate the adverse effects of late-season drought stress. Furthermore, based on the results of the interaction between agronomic management factors x irrigation methods, the Mean wheat grain yield of conventional and conservation agronomic systems at both levels of irrigation methods increased by 22.5% and 34.6%, respectively, demonstrating the superiority of conservation agronomic management over conventional management in water conservation.

Table 6: Interaction of agronomic management treatments, crop sequences, and irrigation methods on wheat grain yield

	Agricultural year				
Agricultural management x Irrigation method	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
Conventional x Normal irrigation	3108a	5653a	5389b	7166a	5577b
Conservational x Normal irrigation	2610a	4122b	6227a	8124a	7853a
Conventional x Terminal drought	2605a	4467ab	4419bc	5382b	5363b
Conservational x Terminal drought	2154ab	4511ab	5106b	5259b	6032ab
	LSD5% 827.9 Kg ha^{-1}		LSD1% 738.3 Kg ha^{-1}		LSD5% 878 Kg ha^{-1}

Based on the results presented in Table 6, it can be concluded that implementing the conservation agronomic management system throughout the current experimental period, under both normal irrigation and Terminal drought stress methods, effectively yielded the highest wheat grain performance compared to the conventional agronomic management system. Specifically, the five-year average increase in wheat grain yield under normal irrigation and Terminal drought stress in conservation agronomic management systems versus conventional ones was 7.6% and 3.7%, respectively. However, the percentage increase in wheat grain yield in the fifth cropping year and after two cropping cycles under normal irrigation and Terminal drought stress, respectively, in conservation agronomic management systems versus conventional ones was 40.8% and 12.5%, indicating the significant role of the conservation agronomic management system in enhancing wheat grain yield under both normal irrigation and Terminal drought stress methods compared to the conventional agronomic management system.



LSD 5%: 1013.9 kg/ha; LSD 1%: 1278.8 kg/ha

Figure 2: Crop sequences x irrigation methods on wheat grain yield means of two crop rotation cycles

Figure 2 shows that despite the lack of significant interaction between crop sequences and irrigation methods, the third crop sequence treatment in both levels of irrigation methods treatment, including normal irrigation and terminal drought, had the highest wheat grain yield compared to its respective treatment levels, emphasizing the relative advantage of implementing the third crop sequence treatment.

Table 7: The combined analysis of variance for wheat grain yield considering years, agricultural managements, crop sequences, and irrigation methods

SOV	DF	MS	F
Year	4	77031689	****
Year (Rep)	9	1448157	-
Agricultural management	1	1235456	ns
Year x agricultural management	4	11623511	****
Rep x agricultural management (Year)	8	1529815	-
Crop sequence	5	2138180	**
Crop sequence x agricultural management	5	1828134	**
Crop sequence x Year	12	1255023	*
Crop sequence x Agricultural management x Year	7	1113791	ns
Rep x Crop sequence (Year x Agricultural management)	46	749771	-
Irrigation method	1	21038933	****
Irrigation method x Agricultural management	1	7904315	****
Irrigation method x Crop sequence	5	721972	ns
Irrigation method x Crop sequence x Agricultural management	5	554266	ns
Year x Irrigation method	4	4294264	****
Year x Agricultural management x Irrigation method	3	1631985	ns
Year x Crop sequence x Irrigation method	11	495624	ns
Year x Agricultural management x Crop sequence x Irrigation mehtod	7	584838	ns
Total	194	3209242	-

CV% 15.99; r^2 Model 95.0; RMSE Model 6.744; Total experiment wheat yield mean: 4658 Kg ha^{-1}

Table 7 shows that, considering the significant effect of year and the interaction of year x agronomic management system on grain yield, it can be concluded that both conventional and conservation agricultural systems exhibited their effects over the course of the experiment, indicating a legacy effect. In other words, it appears that the legacy effect is part of the crop rotation effect, which manifests itself directly and cumulatively in grain yield over consecutive years. Indeed, the crop rotation effect is not attributable to a single factor; rather, it is a combination of different agronomic approaches and managements within the framework of each agricultural system. Furthermore, considering the significant effect of crop sequence and the interaction of agronomic management system x crop sequence, as well as the interaction of year x crop sequence, it can be inferred that to observe the legacy effect of agricultural systems and crop sequences, it is necessary to separately consider each cropping system and the appropriate crop sequence for each system observed, while the location of treatment implementation should remain constant over consecutive years, with crop sequence forwarding only in the time dimension. Additionally, due to the significant effect of irrigation method, it can be concluded that to reduce the adverse effects of terminal drought in the later stages of wheat growth, it is necessary to consider and implement CA management approach by adopting minimum tillage and keeping diverse crop residues within crop sequences to increase soil organic carbon and its microbial activity, indirectly improving soil water retention capacity and other physical, chemical, and biological soil properties, thereby reducing the negative effects of terminal drought on wheat and consequently witnessing less reduction in wheat grain yield. Conversely, due to the significant interaction of year x irrigation method, it can be concluded that continuous terminal drought when repeated in the consecutive years also has a legacy effect on wheat grain yield necessitating to implement CA as the context to mitigate drought stress effects. The statement suggests that there's a significant interaction between the year x irrigation method for wheat grain yield. This implies that continuous terminal drought, when occurring in consecutive years, has a lasting effect on wheat grain yield. Consequently, implementing CA becomes necessary to mitigate the adverse effects of drought stress on crop yield. This conclusion highlights the importance of considering both the temporal aspect (the consecutive occurrence of terminal drought) and the management practice (CA) in addressing the challenges posed by drought stress on cropping system productivity, specifically in wheat cultivation. By recognizing the legacy effects of terminal drought stress and implementing appropriate agricultural practices like CA, farmers can potentially improve system resiliency to drought and maintain or enhance crop yields despite challenging environmental conditions.

Table 8: Overall direct and cumulative (residual) effect of two crop rotation cycles on wheat grain yield in 5th Year of the experiment

Direct effect	Experiment Wheat grain yield difference	Crop sequences Wheat grain yield difference	Wheat grain yield grand mean	Wheat grain yield mean across the years	CV%	r^2
1st year to 5th year wheat	****	ns	3985	3429b	20.20	0.92
2nd year to 5th year wheat	****	ns	5628	3446b	16.70	0.93
3rd year to 5th year wheat	***	ns	5717	5350a	13.20	0.94
4th year to 5th year wheat	ns	**	6372	6483a	8.60	0.97
Cumulative effect (Residual)						
1st crop rotation cycle on 5th year wheat	****	ns	3966	3542b	20.30	0.93
2nd crop rotation cycle on 5th year wheat	****	*	6017	5778a	10.33	0.95
two-rotation cycle on 5th year wheat	****	**	4658	4727ab	15.99	0.95

The wheat grain yield mean in the fifth cropping year was 6206 kilograms per hectare, in statistical class "a".

The results of Table 8, representing the direct and cumulative effects (residuals) of all components of conventional and conservation agricultural systems, as well as the crop sequence, showed that from the first to the fifth cropping year, the direct effect of all experimental factors and the direct effect of crop sequences on wheat grain yield had both increased and decreased, respectively, as indicated in the table8 with their highest and lowest levels of significance. Meanwhile, their coefficients of variation decreased from the first to the fifth cropping year, while the coefficient of determination and the wheat grain yield mean increased.

Overall, wheat grain yields in the first and second biennial cropping cycles, as well as in both biennial cycles, showed significant differences. However, specifically, wheat grain yield in the first biennial period did not show a significant difference by crop sequence, whereas in the second biennial period, the difference was significant at the 5% significance level, and in both cycles, it was significant at the 1% significance level. This indicates that the cumulative (residual) effect resulting from the appropriate and compatible combination of experimental factors can lead to a cumulative positive effect on wheat grain yield over the duration of this study (a synergistic effect), as evidenced by the overall mean grain yield in the first and second cropping cycles. These results are consistent with the views of FAO experts (2013a), suggesting that conservation agriculture is not a single-component technology but rather emphasizes the cumulative effect of all three principles, in line with this study's findings.

Economic Results

The gross profit of wheat in different crop sequences in conventional and conservation agricultural systems showed that the reduction in yield resulting from the application of various treatments predominantly led to a decrease in gross profit. In the conventional agricultural system, the gross profit of wheat in the wheat/maize crop sequence under normal irrigation (2.21 million Rials per hectare), and in the conservation agricultural system, the gross profit of wheat in the wheat/maize-canola/maize crop sequence under normal irrigation (5.22 million Rials per hectare) had higher profits. However, the primary role was related to the maize crop. In fact, profitability depended on the total yield of the crop sequence over the duration and the price of the product. Therefore, the most profitable crop sequence was wheat/maize-canola/maize in the conservation agricultural system. This led to cost reduction, especially in the planting stage, and also resulted in increased yield of forage maize and berseem clover, which could contribute to better land use efficiency (Tables 9 and 10 and Figure 3).

Table 9: Mean present gross profit value of wheat in crop sequences under normal irrigation and terminal drought in conventional agricultural management system in experimental years Unit: Thousand rials per hectare

Crop sequence x Irrigation method treatment	Rep I	Rep II	Rep III	Rep IV	Mean
WM-N	23144	20060	19813	20938	21164
WM-S	22527	19841	17381	18060	19452
WCM-N	4173	4123	3374	4764	4109
WCM-S	4249	4393	3850	4140	4158
WCKM-N	13449	12598	15255	12645	13487
WCKM-S	9365	10780	10363	11374	10470
WMKM-N	23307	19985	21812	15830	20233
WMKM-S	14309	12476	14339	13292	13604
WMKC-N	17287	17617	15286	14528	16180
WMKC-S	12848	13761	11274	14164	13012
WCWM-N	13459	12239	13456	13214	13092
WCWM-S	13205	10646	13020	10759	11917

Table 10: Present gross profit value means of wheat in crop sequences under normal irrigation and terminal drought in conservation agricultural management system in experimental years Unit: Thousand rials per hectare

Crop sequence x Irrigation method treatment	Rep I	Rep II	Rep III	Rep IV	Mean
WM-N	18802	15389	19033	18743	17992
WM-S	21724	15272	18390	19316	18676
WCM-N	3462	3816	3123	1664	3016
WCM-S	3239	3124	3111	1709	2796
WCKM-N	14073	14786	13558	11786	13551
WCKM-S	11607	12970	11013	10638	11557
WMKM-N	26170	22495	20954	20512	22533
WMKM-S	24901	21653	20106	19779	21610
WMKC-N	13226	16531	14258	14678	14673
WMKC-S	10942	16637	12504	14405	13622
WCWM-N	9116	8153	11191	9195	9414
WCWM-S	9100	11324	11908	10161	10623

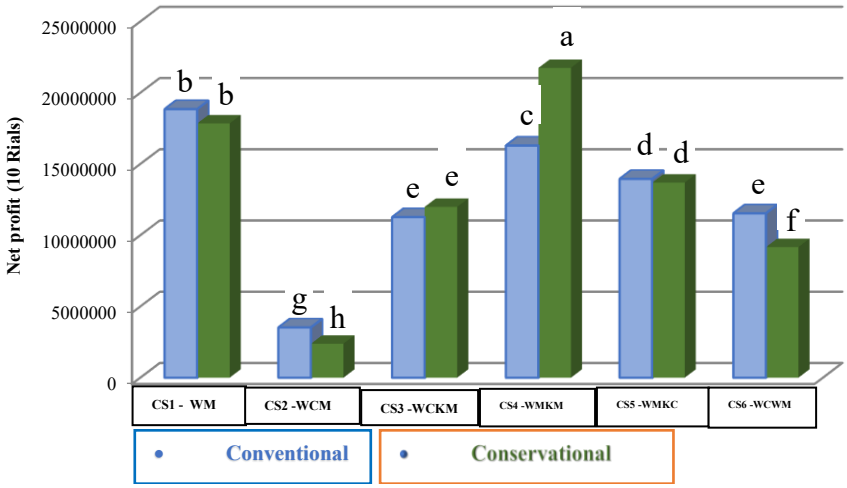


Figure 3: Gross profit of conventional and conservation managements under normal irrigation and terminal drought conditions

Alternative analysis in comparing different crop sequences in the conventional agricultural management system, replacing the selected wheat/maize sequence under normal irrigation (WM-N) with other treatments is uneconomical, as it reduces the present gross profit value of wheat. In comparing different crop sequences in the conservation management, replacing the selected wheat/maize-canola/maize sequence under normal irrigation (WMKM-N) with other treatments is uneconomical, as it reduces the present gross profit value of wheat. In comparing between the two conventional and conservation agricultural management systems, replacing the selected wheat/maize-canola/maize sequence under normal irrigation (WMKM-N) with other treatments is uneconomical, as it reduces the present gross profit value of wheat. The increase in the present gross profit value of wheat in the selected wheat/maize-canola/maize sequence under normal irrigation in the conservation management system compared to the selected wheat/maize sequence under normal irrigation in the conventional agricultural management system was 1.6% higher (Table 11).

Table 11: Replacement analysis of various treatments in crop sequences under normal irrigation and terminal drought in different agricultural management systems in experimental years Unit: Thousand rials per hectare

The result of replacing the selected treatment (crop sequence of wheat/maize-sunflower/maize under normal irrigation (WMKM-N)) by other treatments:	Changes resulting from the substitution of the present value of gross profit from wheat	The present value of gross profit from wheat	Treatment	The agricultural management system
"It is uneconomical, as the present value of gross profit of wheat decreases."	-1369	21164	Crop sequence of wheat/maize under normal irrigation (WM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-3080	19452	Crop sequence of wheat/maize under drought stress (WM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-18424	4109	Crop sequence of wheat/berseem clover/sweet corn under normal irrigation (WCM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-18375	4158	Crop sequence of wheat/berseem clover/sweet corn under drought stress (WCM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-9046	13487	Crop sequence of wheat/berseem clover-canola/corn under normal irrigation (WCKMN)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-12062	10470	Crop sequence of wheat/berseem clover-canola/corn under drought stress (WCKMS)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-2299	20233	Crop sequence of wheat/corn-canola/corn under normal irrigation (WMKM-N)	Conventional
"It is uneconomical, as the present value of gross profit of wheat decreases."	-8929	13604	Crop sequence of wheat/corn-canola/corn under drought stress (WMKM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-6353	16180	Crop sequence of wheat/corn-canola/berseem clover under normal irrigation (WMKC-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-9521	13012	Crop sequence of wheat/corn-canola/berseem clover under drought stress (WMKC-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-9441	13092	Crop sequence of wheat/berseem clover-wheat/corn under normal irrigation (WCWM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-10616	11917	Crop sequence of wheat/berseem clover-wheat/corn under drought stress (WCWM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-4541	17992	Crop sequence of wheat/corn under normal irrigation (WM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-3857	18676	Crop sequence of wheat/corn under drought stress (WM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-19517	3016	Crop sequence of wheat/berseem canola/forage maize under normal irrigation (WCM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-19737	2796	Crop sequence of wheat/berseem canola/forage maize under drought stress (WCM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-8982	13551	Crop sequence of wheat/berseem clover-canola/corn under normal irrigation (WCKMN)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-10976	11557	Crop sequence of wheat/berseem clover-canola/corn under drought stress (WCKMS)	Conservational
"It is uneconomical, as the present value of gross profit of wheat decreases."	-923	21610	Crop sequence of wheat/corn-canola/corn under drought stress (WMKM-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-7860	14673	Crop sequence of wheat/corn-canola/sorghum under normal irrigation (WMKC-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-8911	13622	Crop sequence of wheat/corn-canola/sorghum under drought stress (WMKC-S)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-13119	9414	Crop sequence of wheat/sunflower-wheat/corn under normal irrigation (WCWM-N)	
"It is uneconomical, as the present value of gross profit of wheat decreases."	-11910	10623	Crop sequence of wheat/sunflower-wheat/corn under drought stress (WCWM-S)	

Conclusion

Based on the obtained results, the average wheat grain yield during the study period in the conservation agricultural management system was 2.5% higher than the conventional agricultural management system. The most profitable crop sequence of wheat/maize - canola/maize was observed in the conservation agriculture management system under normal irrigation. The present gross profit mean value of Parsi wheat cultivar in this crop sequence under normal irrigation was estimated at 22.53 million rials per hectare during the experimental period. Therefore, in Alborz province, the crop sequence of wheat/maize - canola/maize is recommended as the most profitable crop sequence for the CA management system, and the wheat/maize sequence is recommended for the conventional agriculture management system in the target area. Comparing the current results with the findings of other studies, Johnson et al. (2003) also assumed that the inclusion of oilseeds such as canola and sunflower in rotation with wheat has positive and beneficial effects on wheat performance. For example, improving wheat grain yield in the sequence after canola ranged from 24 to 30% compared to monoculture wheat conditions, which is consistent with the results of this study.

Conflicts of interest

There are no conflicts of interest of any type in drafting this review paper.

Author's contribution

Authors contributed equally in conceived and design the analysis, collected the data, performed the analysis and wrote the full length paper.

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